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MEMORANDUM REPORT

THE ANALOGY BETWEEN SURFACE WAVES IN A LIQUID AND SHOCKS IN COMPRESSIBLE GASES

EXPERIMENTAL STUDY OF WAVE FORMS

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I INTRODUCTION

The subject matter covered in this report concerns the characteristics of the surface waves produced in the ripple tank by the wave generators and the effect on the wave form of adding detergents to the working fluid. The results will be presented under the following headings:

1. Experimental procedure.
2. The wave generators.
3. Variables affecting wave strength.
4. Effect of adding detergents to working fluid.
5. Summary and conclusions.

II EXPERIMENTAL PROCEDURE

The experimental procedure is essentially that indicated in previous progress reports[1,2*]. Electrodes placed in the ripple tank in the path of the wave enable a depth-time curve to be recorded on a recording oscillograph. Consistent calibration curves were obtained for the three electrodes if care was taken in cleaning the electrodes and if sufficient time was allowed for the oscillograph power supply to stabilize (1/2 to

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* Superscripts refer to the bibliography at the end of this report.

3/4 hour).

The measurement of wave strength necessitates the determination of the ordinate of the depth-time curve from the oscillograph. Two factors tend to introduce error into the measurement of wave strength and thus influence reproduction of a wave of given strength.

The first factor is the lack of smoothness of the after-wave surface for strong and very weak waves. The strong shocks leave a rough and turbulent wake (Fig. 1a), while the very weak shocks are accompanied by secondary waves which create an oscillatory surface behind the shock front (Fig. 1b). This factor necessitates averaging the wave form by means of a somewhat arbitrary smooth curve before measurements can be made.

The second factor is a decay in strength as the shock progresses. This effect is more pronounced when a large diameter air inlet is employed on the generator; i.e., when the generator discharges rapidly. Under this condition, the capacity of the generator reservoir is not sufficient to keep the water depth constant behind the wave front until the wave has passed beyond the last measuring point. Thus, an instantaneous section through the shock wave shows an after-wave surface which slopes downward toward the rear. This lack of continual reinforcement results in a decrease in the strength of the shock as it progresses. The decay of wave strength is not so pronounced for the waves created under conditions which assure a continual discharge of water from the generator until the wave passes the last measuring point (Fig. 1c). In reproducing or comparing waves with a marked decay in strength, it is important to make corresponding measurements at the same distance from the generator.

The velocities of a number of shock waves were calculated from the oscillograph records and compared with the theoretical value given by the equation (cf. any text on hydrodynamics):

$$C = \left[\frac{gh_0}{2}\frac{h_1}{h_0}\left(\frac{h_1}{h_0} - 1\right)\right]^{\frac{1}{2}}$$

where C = wave velocity

h_0 = initial depth of liquid ahead of wave

h_1 = depth of liquid behind wave

The experimental value of velocity was in all cases higher than the theoretical value. A difference of as much as 5 per cent was found in the case of some strong waves. It has been suggested that this discrepancy is caused by a jet effect near the generator due to the fact that the velocity of the water as it leaves the generator is normally greater than the velocity of the wave generated. Also to be considered, however, is the effect of the wave strength decay. The velocity computed from the experimental record is necessarily an average value, and since the wave strength is decreasing throughout the measured distance, the problem arises of selecting the proper wave strength to use in the calculation of the theoretical velocity. For the weaker waves where the decay in strength is not so pronounced, the discrepancy between experimental and theoretical values of velocity is less than 2 per cent.

III THE WAVE GENERATORS

The wave generators are those mechanisms described in the previous progress report[2] (Fig. 2). The generator is 24 in. long and makes wave fronts of the same length. The reservoir into which the water is drawn prior to its release is 24 in. long, 9 in. high, and has a variable cross-section as indicated in Fig. 2. Air inlet valves are located at the quarter points of the top surface. These valves are opened by springs tripped by electrical solenoids. The valve openings are throttled by means of removable orifice plates. The water is made to rise inside the generator by reducing the pressure by means of a suction pump. The face of the discharge slot is milled from heavy brass tubing, thus providing for a uniform discharge through the full length of the slot. The body of the generator can be lifted by means of a rack and pinion to vary the height of the discharge slot.

IV VARIABLES AFFECTING WAVE STRENGTH

A series of waves were generated to determine the effect upon wave strength of the following variables: (1) the general water level in the ripple tank; (2) the height to which water is drawn in the generator; (3) the diameter of the air inlet orifice; (4) the height of the discharge slot.

The more important variables are the initial depth of water in the ripple tank and the air inlet diameter. Their effect upon wave strength is indicated in Fig. 3. It is seen that a given wave strength can be obtained by a suitable choice of initial water depth and air inlet diameter. There is usually more than one combination of initial water depth and air inlet diameter which will produce a wave of given strength; however, because of the wave strength decay previously mentioned, more satisfactory results are obtained by using small diameter air inlets on the generators.

A larger amount of data was available for the 1/4 inch diameter air inlet; as presented in Fig. 4 this data suggests a linear relation between wave strength and initial water depth for initial water depths up to 20 millimeters.

In Fig. 5 is indicated the effect upon wave strength of generator head, i.e., the height to which water is raised in the generator reservoir before release. In general, the effect seems to be negligible within experimental error for a generator head above 18 centimeters. A large generator head is desirable to minimize the decay of wave strength caused by lack of continual reinforcement of the wave.

The height of the discharge slot was found to have a negligible effect upon wave strength. However, it has been found that the height of the discharge slot is important, especially for strong waves, since if the wave is created through too narrow a slot the resulting effect is that of a jet of water overriding the still water.

The ability of the two available generators to create identical waves is within experimental error provided a generator head of 19 to 21 centimeters is used.

V EFFECT OF ADDING DETERGENTS TO WORKING FLUID

The working fluid used in the ripple tank is a solution (0.001 to 0.002 normal) of manganous chloride in distilled water, the salt being added to give more uniform electrolytic characteristics when the oscillograph method of depth measurement is used. The waves generated in this fluid, however, had rough surfaces and the slopes of the wave fronts were not so steep as desired (Fig. 6a).

In an attempt to improve wave shape and decrease roughness, 0.5 per cent by volume of a prepared solution of isoquinolium bromide was added to the working fluid. Waves created in the resulting fluid had the desired smoothness and a substantially increased wave-front slope (Fig. 6b); however, two disadvantages were apparent. First, suds were formed by each generated wave, and the resulting bubbles would interfere with photographic procedures. Second, the secondary waves accompanying the weaker shocks were also intensified, these secondary waves becoming evident with stronger shock waves than had been the case with no detergent. The range of strengths giving desirable wave forms thus shifted to higher values, an unsatisfactory situation in view of the fact that future plans are to investigate as weak waves as possible.

To obtain an intermediate effect, 0.5 per cent by volume of Kodak Photo-Flo (an aerosol solution) was added to the distilled water. Waves created in this fluid had the desired smoothness and a substantial increase in wave-front slope when compared with corresponding waves made in distilled water (Fig. 6c). The advantage lay in the absence of bubbles to interfere with photographic procedures, and in the possibility of obtaining weaker waves with more satisfactory form than were possible in the isoquinolium bromide solution.

The use of these detergents had no measurable effect on either the velocity or the strength of the waves.

VI SUMMARY AND CONCLUSIONS

Measurements to determine wave strength and velocity should not be made too near the generator: a distance greater than 20 inches is desirable.

A wave of given strength can be generated by a proper choice of initial water depth in the ripple tank and of air inlet diameter on the generator. To minimize decay of wave strength, a large generator head and a small air inlet diameter should be used. Waves identical within experimental error will be created by the two available generators if the water is raised in the generators to a height between 19 and 21 centimeters.

The addition of a detergent to the working fluid results in smoother waves and steeper wave fronts for shock waves of intermediate strength, but causes accentuation of the oscillatory nature of weaker waves.

BIBLIOGRAPHY

1. Einstein, H. A., and Baird, E. G., "Progress Report of the Analogy between Surface Shock Waves on Liquids and Shocks in Compressible Gases", Hydrodynamics Laboratory, Calif. Institute of Technology, Sept. 15, 1946.

2. Einstein, H. A., and Baird, E. G., "Progress Report of the Analogy between Surface Shock Waves on Liquids and Shocks in Compressible Gases", Hydrodynamics Laboratory, Calif. Institute of Technology, July 30, 1947.

Fig. Ia – A STRONG WAVE WITH ROUGH AND SLOPING AFTER-WAVE SURFACE

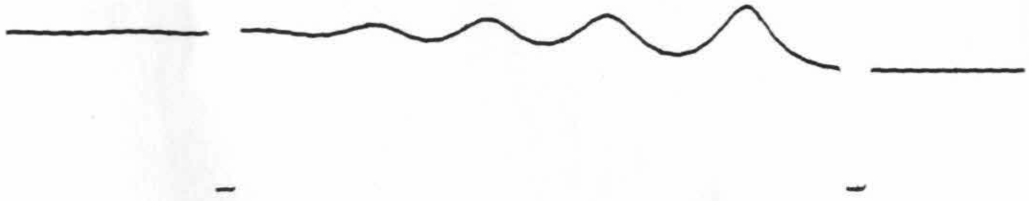


Fig. Ib – A WEAK WAVE WITH SECONDARY WAVES

Fig. Ic – A SATISFACTORY WAVE FORM

Fig. 2 — THE WAVE GENERATOR

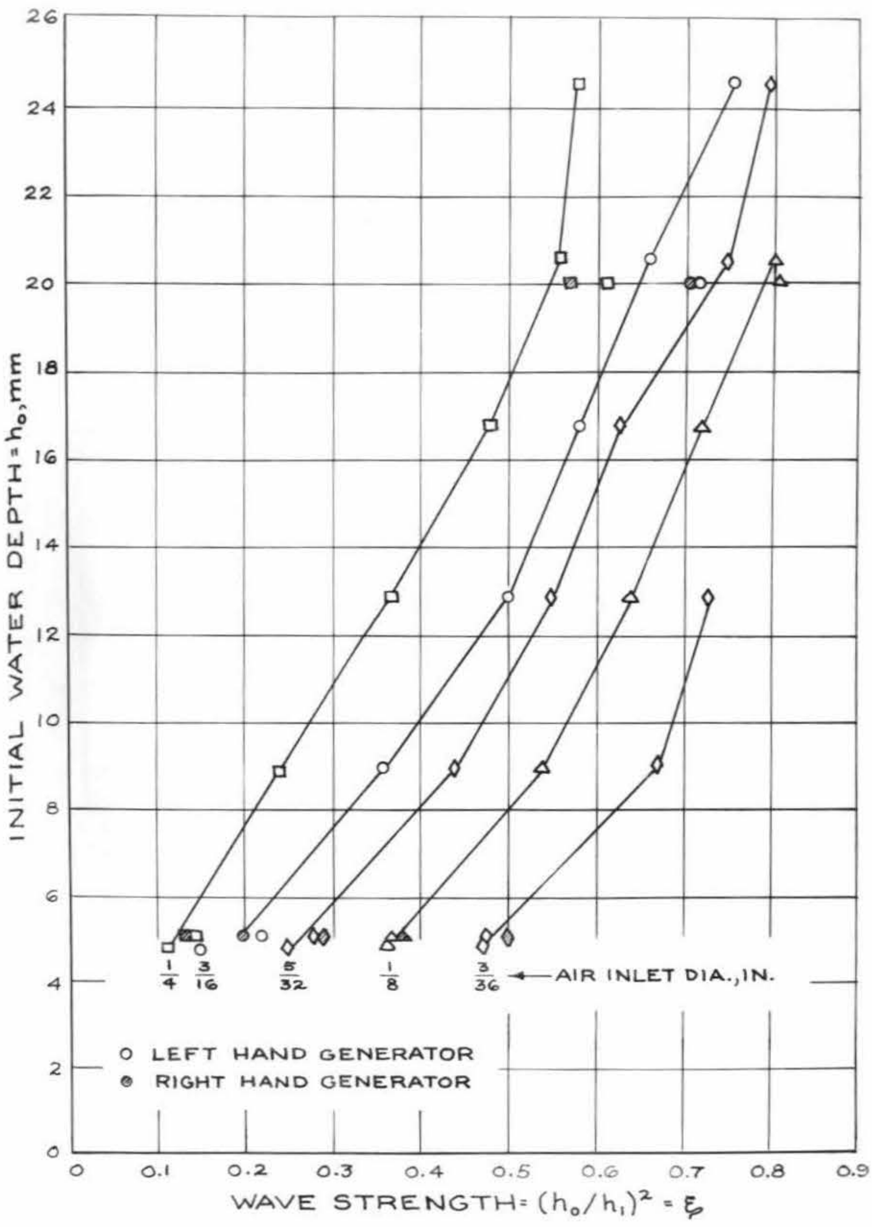


Fig. 3 — EFFECT UPON WAVE STRENGTH OF INITIAL WATER DEPTH AND DIAMETER OF GENERATOR AIR INLET

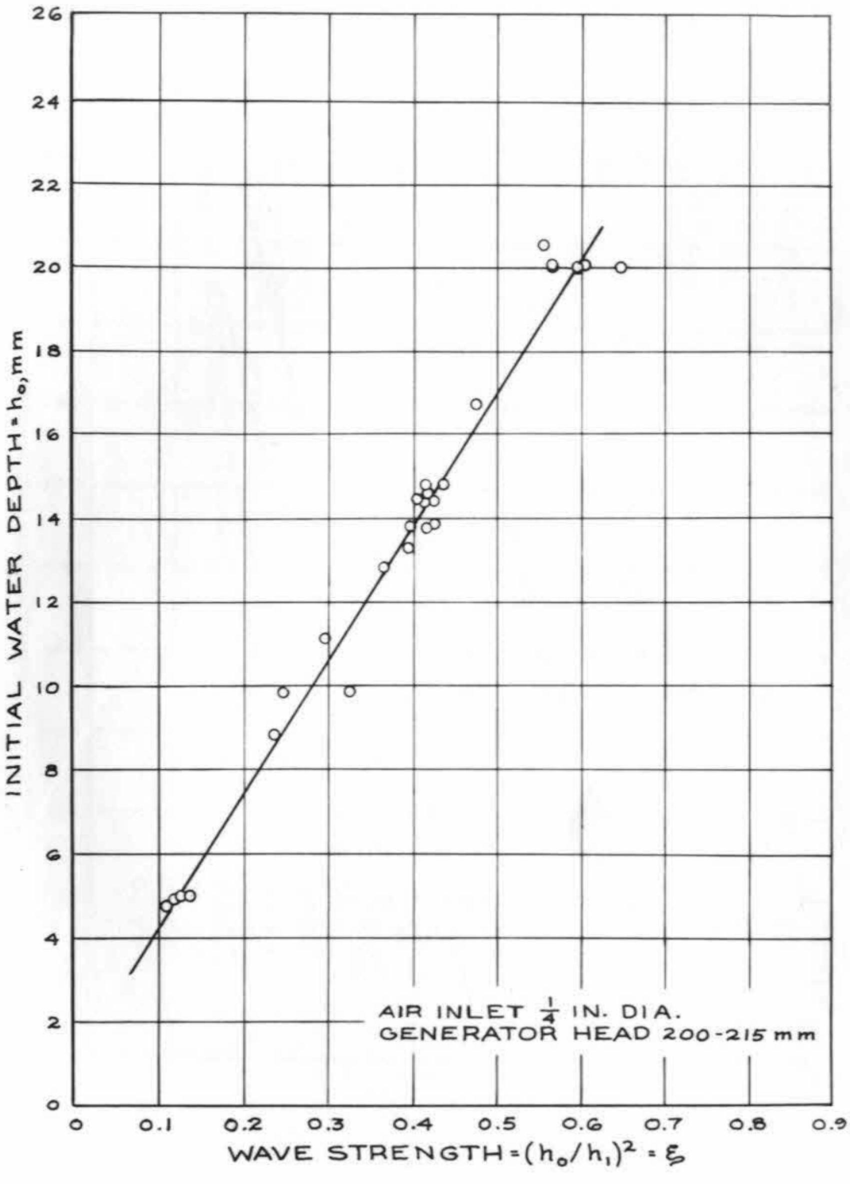


Fig. 4—EFFECT UPON WAVE STRENGTH OF INITIAL WATER DEPTH FOR 1/4 INCH DIAMETER GENERATOR AIR INLET

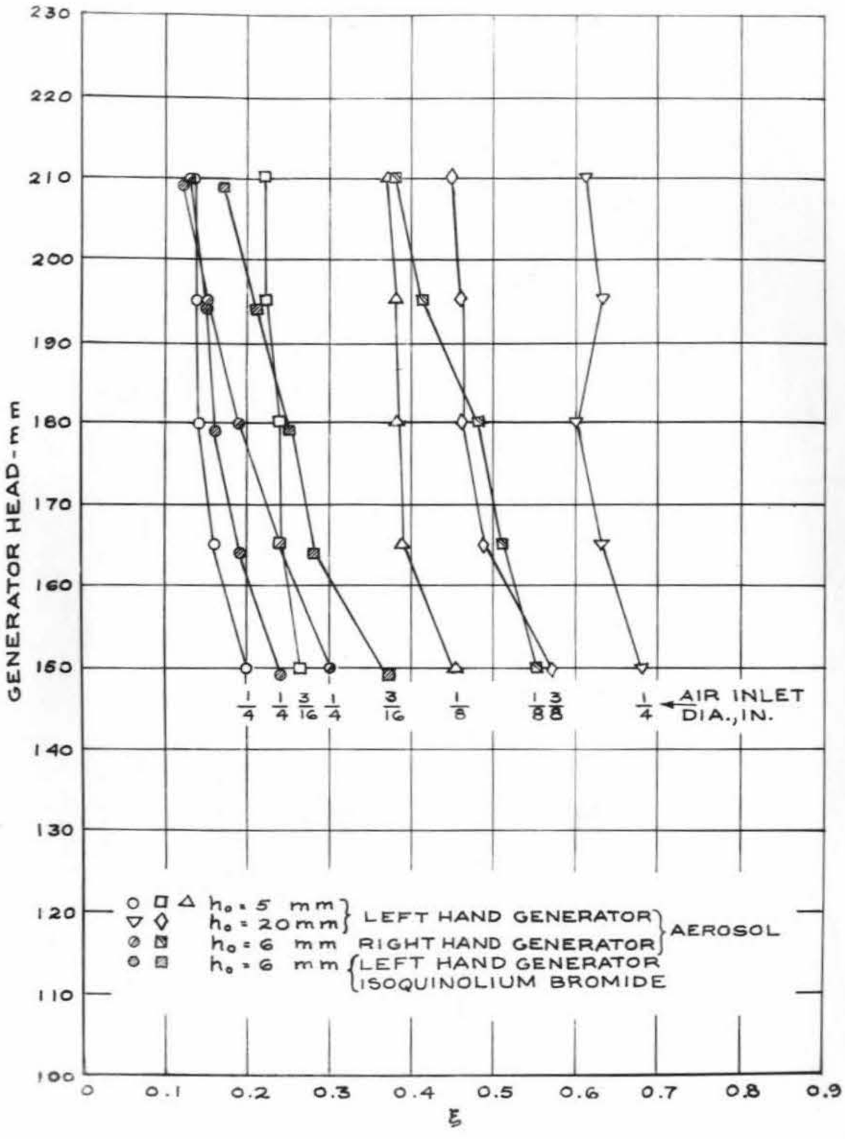
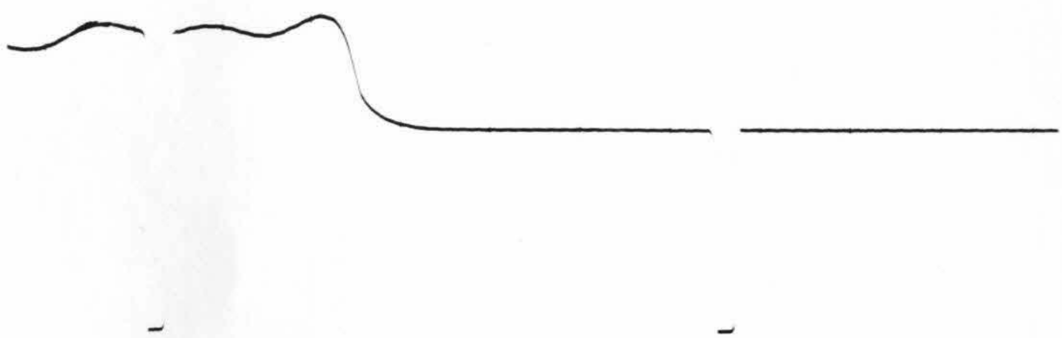
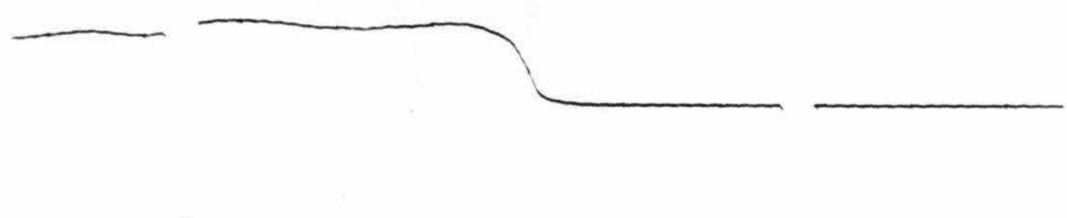


Fig. 5—EFFECT UPON WAVE STRENGTH OF HEIGHT TO WHICH WATER IS RAISED IN GENERATOR

a. DISTILLED WATER



b. ISOQUINOLIUM BROMIDE SOLUTION



c. AEROSOL SOLUTION

Fig. 6—COMPARISON OF SIMILAR WAVES GENERATED IN DIFFERENT FLUIDS